ABSORPTION OF ULTRA HIGH FREQUENCY WAVES IN SALT SOLUTIONS

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ABSTRACT. Percentage of absorption and reflexion suffered by a u.h.f waves (300-480 Mc/s), in aqueous solutions of magnesium sulphate and calcium chloride have been determined Absorption index, attenuation coefficients and reflexion coefficients for various frequencies at different concentrations of the solutions have been calculated Experimental data have been utilised to calculate dielectric constant, loss tangent and absorption conductivity of the solutions at different frequencies and concentrations Values of molar conductivity for magnesium sulphate have been calculated Values of relaxation time obtained from experimental data have been compared with those calculated theoretically Reflexion coefficient show very little variation for different concentration and frequency Molar conductivity increases with frequency over the range in question

EXPERIMENTAL

The present paper forms a part of an investigation on the behaviour of sea water as a medium of propagation of u.h.f. waves. The object of the present investigation is to study the percentage of absorption and reflexion undergone by a u.h.f. wave while travelling through aqueous solution of magnesium sulphate and calcium chloride of different concentrations. Experimental detail involving description of equipments and principle of the method followed is under publication, (Chatterjee and Sreekantan, 1948 a). Observed percentage of absorption suffered by the wave in travelling through the solutions for different normalities at particular frequencies are recorded in Figs. 1 and 2.

In order to determine the attenuation coefficient, values of percentage of transmission are plotted against various depths (up to 5 cms.) of solution for different concentrations and frequencies. The slope of the average curve between the two extreme envelopes gives the attenuation coefficient α (Chatterjee and Sreekantan, 1948 b). Values of α found from different portions of the curve will be different. Slope between 2 to 3 cms. of liquid give values for α which agree more closely with theoretical valves. The values of absorption indices k at different frequencies and normalities can be calculated from the following relation :—

$$\alpha = \frac{2\pi n k}{\lambda}$$

involving refractive index n and wavelength λ. The values of reflexion coefficients R for normal incidence can be calculated from the following relation :—

$$R = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2}$$

obtained from Fresnel's equation.

Values of α, k and R for both the solutions at four frequencies and three different concentrations have been given in Table I. Values of n used in the above calculation have been calculated from the values of ϵ' (Table V).

TABLE I

Normality = 0.09N for $MgSO_4$ and 0.1N for $CaCl_2$

Frequency in Mc/s	α		k		R	
	$MgSO_4$	$CaCl_2$	$MgSO_4$	$CaCl_2$	$MgSO_4$	$CaCl_2$
340	0 1081	0 0385	0 1654	0 059	0 6476	0 6418
400	0 1260	0 094	0 1616	0 125	0 6457	0 6393
440	0 1138	0 130	0 1711	0 164	0 6456	0 6415
480	0 1065	0 0804	0 1164	0 088	0 6139	0 6406
Normality = (0 125 N)						
340	0 0618	0 073	0 0934	0 129	0 6507	0 6431
400	0 2351	0 0967	0 3022	0 127	0 6486	0 6406
440	0 0849	0 1709	0 0996	0 205	0 6480	0 6412
480	0 811	0 0572	0 1100	0 063	0 6471	0 6409
Normality = 0.166N for $MgSO_4$ and 0 2N for $CaCl_2$						
340	0 0390	0 0495	0 0585	0 071	0 6562	0 6448
400	0 1086	0 0598	0 1361	0 078	0 6518	0 6424
440	0 1079	0 1189	0 1100	0 142	0 6500	0 6421
480	0 1361	0 047	0 1462	0 052	0 6486	0 6430

DISCUSSION

Figs. 1 and 2 show that absorption maxima generally shift towards higher concentration with increasing frequency. This is to be expected from the theoretical point of view. If the absorption maximum is regarded as taking place when $\omega\tau$ is unity, then shifting of absorption peak towards higher concentration, as the frequency becomes higher, should occur as the relaxation time τ is reduced with increasing concentration. It will further be observed that the concentrations at which maximum absorption occurs for $MgSO_4$ are 0.090 N, 0 111 N, 0.125 N and 0.166 N for frequencies 340, 440, 460 and 480 Mc/s respectively. Whereas for $CaCl_2$ the concentrations of maximum absorption are 0.105 N, 0.115 N, 0.18 N, 0.20 N and 0.21 N for

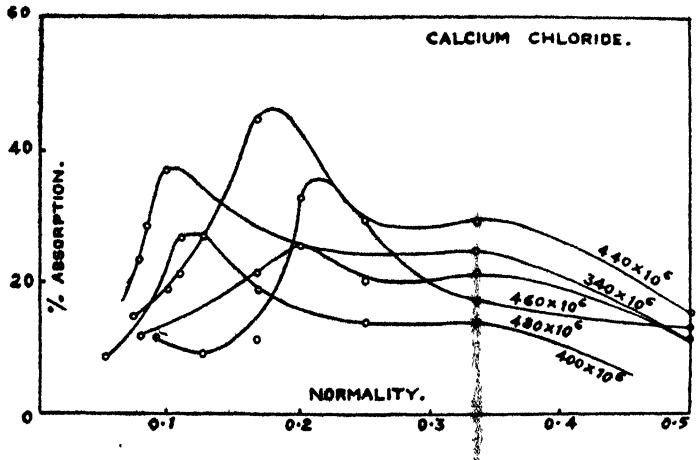

FIG. 1

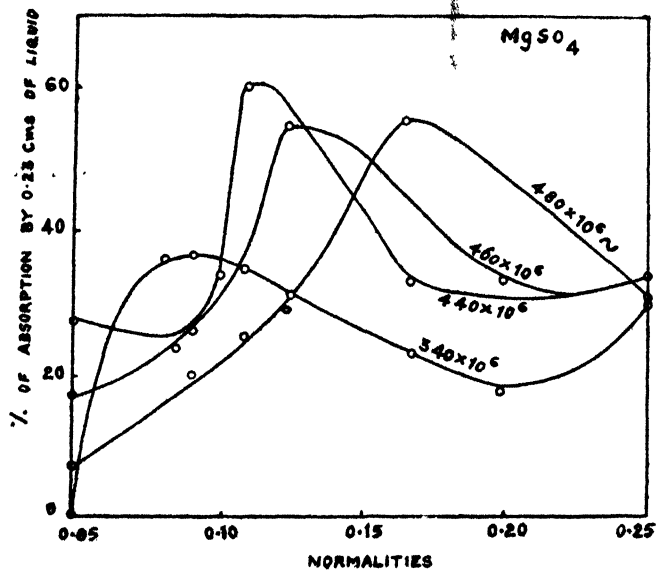

FIG. 2

frequencies 340, 400, 440, 460 and 480 Mc/s respectively. It will be evident from Table II that the product of wavelength λ and the corresponding concentration, γ^* at which the absorption is maximum, varies with frequency in both the cases. In case of $CaCl_2$ the product at 75 cm. wavelength is 8.625, whereas the value recorded by Forman and Crisp (1946) is 8.00 for 80 cm. wavelength.

Besides the interest of wave propagation, study of absorption leads to the insight of molecular structure. This may be gained from an investigation of dielectric behaviour of the solutions at different frequencies. This amounts

TABLE II

λ cms.	λ.γ*	
	$MgSO_4$	$CaCl_2$
88 2	8.018	9.260
75.0	...	8.625
68 2	7 577	1[illegible].276
65 2	8.150	13.04
62 5	10.410	13.125

to a study of the frequency dependence of dielectric constant and loss tangent of the solution. Though different approach has been made by different authors to explain the mechanism of absorption, they lead to some form of relaxation function. Therefore, the time of relaxation giving a measure of the rate of restoration of random order after removal of the applied field is of interest.

The absorption maximum, or in Debye's notation ϵ'' maximum takes place when $\omega\tau = 1$, or more correctly, when

$$\omega\tau = \frac{\epsilon_\infty + 2}{\epsilon_0 + 2} \qquad \ldots \quad (1)$$

which can be deduced from Debye's (1929) expression

$$\epsilon = \epsilon' - j\epsilon'' \qquad \ldots \quad (2)$$

for generalised dielectric coefficient.

For the strengths of solution employed ϵ_∞ may be regarded as equal to the dielectric constant of water (80) at u.h.f. Values of dielectric constant ϵ_0 at low frequencies have been calculated (Table III) from the following relation given by Falkenhagen (1934) :—

$$\epsilon_{\omega=0} - \epsilon_s = \frac{1.97 \times 10^6 |z_1 z_2| \{|z_1| + |z_2|\}^{\frac{1}{2}} . (q^*)^{\frac{1}{2}}}{2\epsilon_s^{\frac{1}{2}} . T^{\frac{3}{2}} . \left(1 + \frac{1}{\sqrt{q}}\right)^2} \qquad \ldots \quad (3)$$

where z_1 = valence of Mg or Ca ion

z_2 = valence of SO_4 or Cl ion

$T = 300^\circ$ A

ϵ_s = dielectric constant of water (80)

$q = 0.5$ for $MgSO_4$ and 0.421 for $CaCl_2$ respectively

γ^* = concentration in gm. eq. per litre

Substituting proper values, eq. (3) may be written as follows

$$\left(\epsilon_{\omega=0}-\epsilon_s\right)^{23°C}_{MgSO_4} = 28.95\sqrt{\gamma^*} \quad \ldots (4)$$

$$\left(\epsilon_{\omega=0}-\epsilon_s\right)^{23°C}_{CaCl_2} = 10.41\sqrt{\gamma^*} \quad \ldots (5)$$

TABLE III

$MgSO_4$		$CaCl_2$	
γ^*	$\epsilon_{\omega=0}$	γ^*	$\epsilon_{\omega=0}$
0.090 N	88.728	0.105 N	83.375
0.111 N	89.638	0.115 N	83.521
0.125 N	90.230	0.118 N	84.428
0.166 N	91.810	0.20 N	84.656
–	–	0.21 N	84.772

values of $\tau_{obs.}$ for different concentrations (Table IV) have been calculated by using equation (1) and Table III. Values of τ_{cal} for same concentrations, have also been calculated by using the following Deby-Falkenhagen (1934) relation

$$\tau = \frac{8.85 \times 10^{-11} \cdot \epsilon_s}{\Lambda_\infty \cdot \gamma^*}$$

involving equivalent conductivity Λ_∞ of solution at infinite dilution, concentration of solution γ^* expressed in gm. eq. per litre and dielectric constant of water $\epsilon_s = 80$

TABLE IV

Frequency in Mc/s of max absorption.	$MgSO_4$		$CaCl_2$	
	$\tau_{cal} \times 10^{10}$ secs.	$\tau_{obs} \times 10^{10}$ secs	$\tau_{cal} \times 10^{10}$ secs.	$\tau_{obs} \times 10^{10}$ secs.
340	6.861	4.232	5.714	4.196
400	–	–	5.208	3.815
440	5.614	3.236	3.558	3.432
460	4.990	3.077	2.995	3.062

The frequency dependence of dielectric properties of the solutions can be studied by substituting the observed values of τ from Table IV in eq. (2), where ϵ' and ϵ'' are given by the following relation

$$\epsilon' = \epsilon_\infty + \frac{\epsilon_0 - \epsilon_\infty}{1 + x^2} \quad \ldots (6)$$

$$\epsilon'' = \frac{\epsilon_0 - \epsilon_\infty}{1 + x^2} . x \quad \ldots (7)$$

where $x = \omega\tau . \frac{\epsilon_0 + 2}{\epsilon_\infty + 2}$

Values of ϵ' for different concentrations at different frequencies are given in Table V.

TABLE V

Frequency in Mc/s	Values of ϵ' at different normalities						
	$MgSO_4$			$CaCl_2$			
	0.09 N	0.11 N	0.125 N	0.105 N	0.115 N	0.18 N	0.20 N
340	84.364	86.034	86.616	81.688	82.045	82.709	83.010
400	83.631	85.278	85.825	81.415	81.760	82.425	82.652
440	83.324	84.819	85.291	81.262	81.593	82.214	82.430
460	83.055	84.608	85.114	81.192	81.517	82.164	82.330
480	82.890	84.401	84.897	81.128	81.443	82.021	81.320

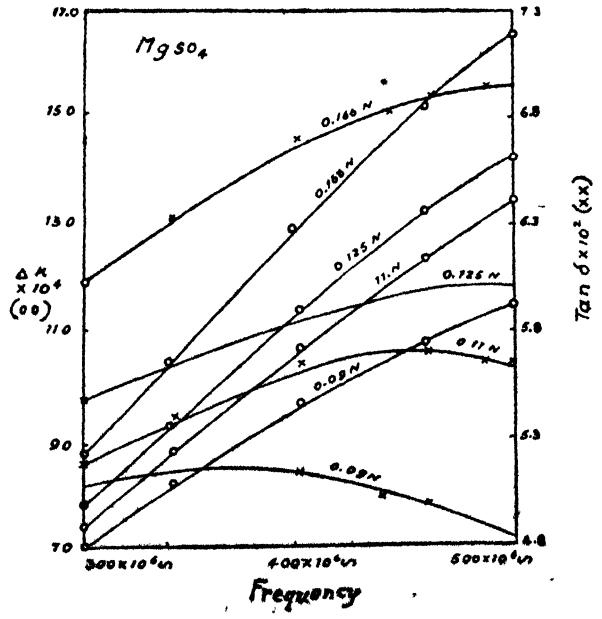

FIG. 3

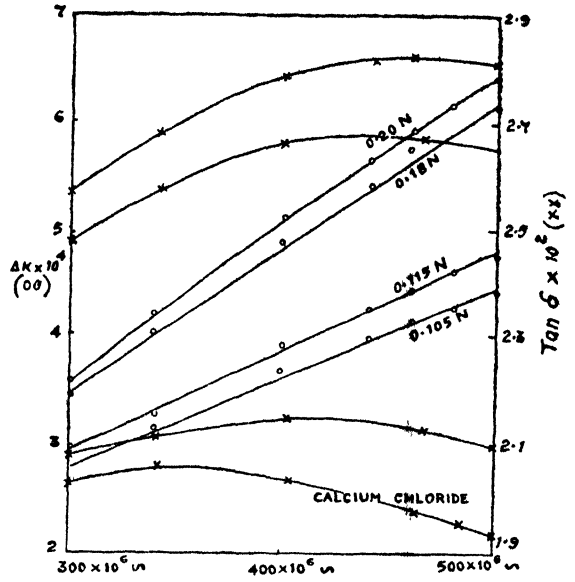

FIG. 4

Values of tan $\delta = \epsilon''/\epsilon'$, calculated from eqns. (6) and (7) are given in Figs. 3 and 4. Values for absorption conductivity Δk have been calculated from the following relation (Sharbaugh and others, 1947)

$$\Delta k = \frac{(\epsilon_0 - \epsilon_\infty).\nu^2/\nu^2_c}{(1 + \nu^2/\nu^2_c) \times 1.80 \times 10^{12}}$$

where $$\nu_c = \frac{\epsilon_\infty + 2}{\omega\tau(\epsilon_0 + 2)}$$

Variation of Δk with frequency for various values of concentrations (Figs. 3 and 4) shows an increase with frequency.

Variations of molar conductivity with frequency for both the solutions have also been studied with the help of the following relation (Falkenhagen, 1934)

$$\Lambda_\omega = \Lambda_\infty - \Lambda_{1\omega}\Lambda_{11}$$

The calculation shows an increasing value of conductivity with frequency increasing. The increase of conductivity with frequency may be explained in the following way. When an electrolyte is subjected to an alternating electric field, each ion will execute an oscillatory motion. When the exciting field frequency is low, the spherical symmetry of the steady state distribution will be disturbed and at any moment the symmetry of the charge distribution will correspond to the instantaneous velocity of the ion. If the frequency of the exciting field is great enough, so that the period of oscillation is comparable to relaxation time, the charge distribution of the ionic atmosphere will tend to correspond to the unperturbed state symmetry and hence the conductance will increase with increasing frequency. Or in other words, the part due to

relaxation force, given by (Falkenhagen, 1934) the following expression

$$\Lambda_{1\omega} = \frac{|e_1 e_2|}{3D_0 kT} . k^1 . \Lambda_\infty \times \text{Real part of } x,$$

decreases with frequency increasing and may vanish if the frequency of the impressed field is considerably high. In this case the expression for molar conductivity reduces to $\Lambda_\omega = \Lambda_\infty - \Lambda_{11}$. Or in other words, molar conductivity, within the frequency range in question, exceeds the low frequency value by $\Lambda_{1\omega}$

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REVIEW

Electron and Nuclear Counters.—S. A. Korff, New York : Van Nostrand Co. ; London : Macmillan & Co. 1948, pp. IX, 212 illustrated, $ 3.25, 18 s.

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